Continuous Atlanta Fleet Evaluation
(CAFÉ)

Final Report
(Draft for Sponsor Comment)

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Introduction

This report summarizes the results from the Continuous Atlanta Fleet Evaluation (CAFÉ) remote sensing measurements made during fourth quarter of calendar year 2004 and first three quarters of calendar year 2005, the period of the 2004-2005 CAFÉ contract. CAFÉ is sponsored by the Mobile and Area Sources Program of the Georgia Department of Natural Resources (DNR) with the primary purpose of evaluating on-road emissions as an aid in evaluating and strengthening various mobile source emissions control programs including vehicle Inspection and Maintenance (I/M) programs. The remote sensing measurements conducted as part of CAFÉ were made using a remote sensing device (RSD) operated a selected locations in metropolitan Atlanta, GA area and in Augusta and Macon, GA. This RSD is capable of measuring CO, CO2, HC, and NOx from motor vehicle exhaust as the vehicles pass the device, as well as speed and acceleration of vehicles passing the system. The RSD is also equipped with a digital video system that allows for capturing images of vehicle license plates for use in analysis of the measurements. All of the remote sensing measurements and data analysis activities in the 2004-2005 CAFÉ program were conducted by the Air Quality Branch (formerly Air Quality Laboratory) of the Georgia Tech Research Institute under contract with DNR.

CAFÉ measurements were collected during 62 days of field measurements on 28 sites (Appendix A). Sites were selected to approximate overall fleet characteristics including county population and socio-demographic characteristics. Remote sensing sites were also selected to fit meet the physical sampling characteristics needed for the RSD. These included: a single direction of traffic flow, a positive roadway slope, as well as positive vehicle power demand as well as other characteristics designed to maximize the probability of a successful measurement. In addition, the sites must provide a safe working environment for the remote sensing crew.

During 2004-2005 CAFÉ compiled at total of 385,596 measurements. Of these, 350,527 records produced a valid reading with measurements of at least CO and CO2. Details of data collection can be found in Appendix C. The resulting database meet or exceeded the quality standards of all previous collection efforts.

Data Collection

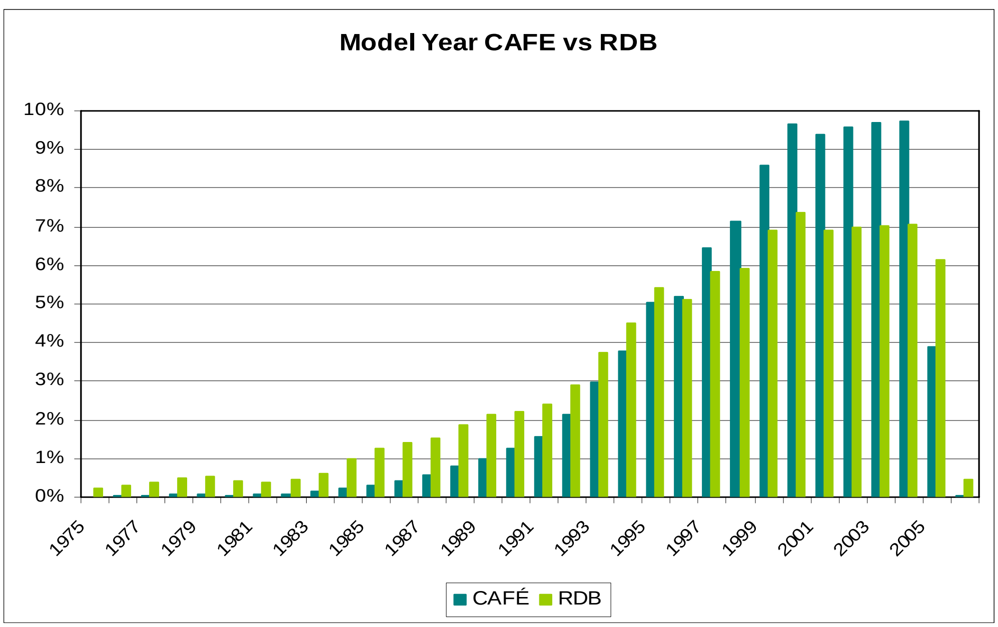
In a typical data collection operation, the RSD system is located beside the sampling location and measurements of the principal motor vehicle emissions (carbon monoxide, nitrogen oxides, non-methane hydrocarbons and carbon dioxide) are made using non-dispersive infrared (NDIR) spectroscopy. These measurements along with accompanying images of motor vehicle license tag for the vehicles in collection are cross-referenced and stored electronically. Upon return from the deployment, the digital license tag images are manually read and license tag numbers are recorded for comparison with the Georgia Motor Vehicle registration database (RDB). Readable Georgia registered license plates are matched with the RDB to provide Vehicle identification Numbers (VINs) that are decoded to provide information on vehicle characteristics including model-year, make, model and body type for inclusion in a measurement database along with the emissions readings, date, time, measurement location and vehicle speed and acceleration. Both before and after production of this database, the data are subjected to a variety of quality assurance and quality control (QA/QC) procedures to ensure the validity of the measurements.

Validity of Fleet Comparisons

While the QA/QC program is aimed at ensuring that the individual measurement are accurate and precise, this does not ensure that the overall sampling program is producing a representative sample of vehicles for fleet comparisons. To evaluate the degree to which the data can be used for these purposes, we must first evaluate how closely the fleet that we are sampling is representative of the overall fleet. We must also show that the different fleets groups can be compared to one another.

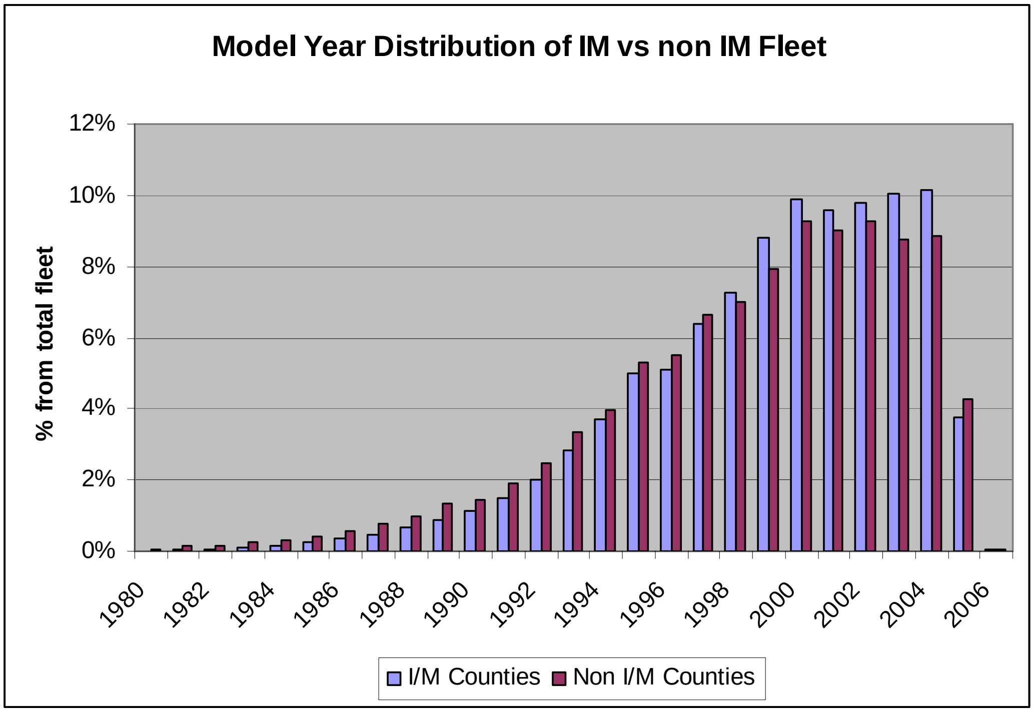
Figure 1 shows model year distribution for fleet measured by remote sensor and full Georgia fleet. To achieve this task we used Registration Database (RDB) of State of Georgia for third quarter of 2005. Observed during measurements vehicles have very similar distribution to registered Georgia fleet when the decline of motor vehicle activity with vehicle age is considered.

Figure1. Comparison of Observed and Registered Fleets



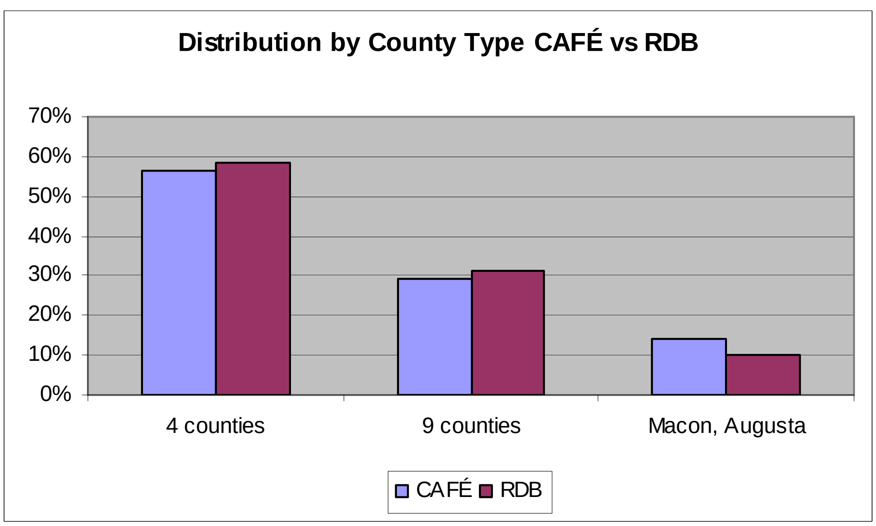
The “inspected” (i.e. subject to I/M testing) Atlanta fleet and “un-inspected” fleets of Macon-Augusta and counties around Atlanta fleets are also very similar. Figure 2 shows that two fleets have virtually the same model year distribution.

Figure 2. Comparison of Inspected and Un-inspected Fleets



We also examined distribution of vehicles measured by county groups and vehicles registered in those counties (Figure 3). Once again they are very similar, which further proves that our sample is representative and valid for analysis of the I/M program.

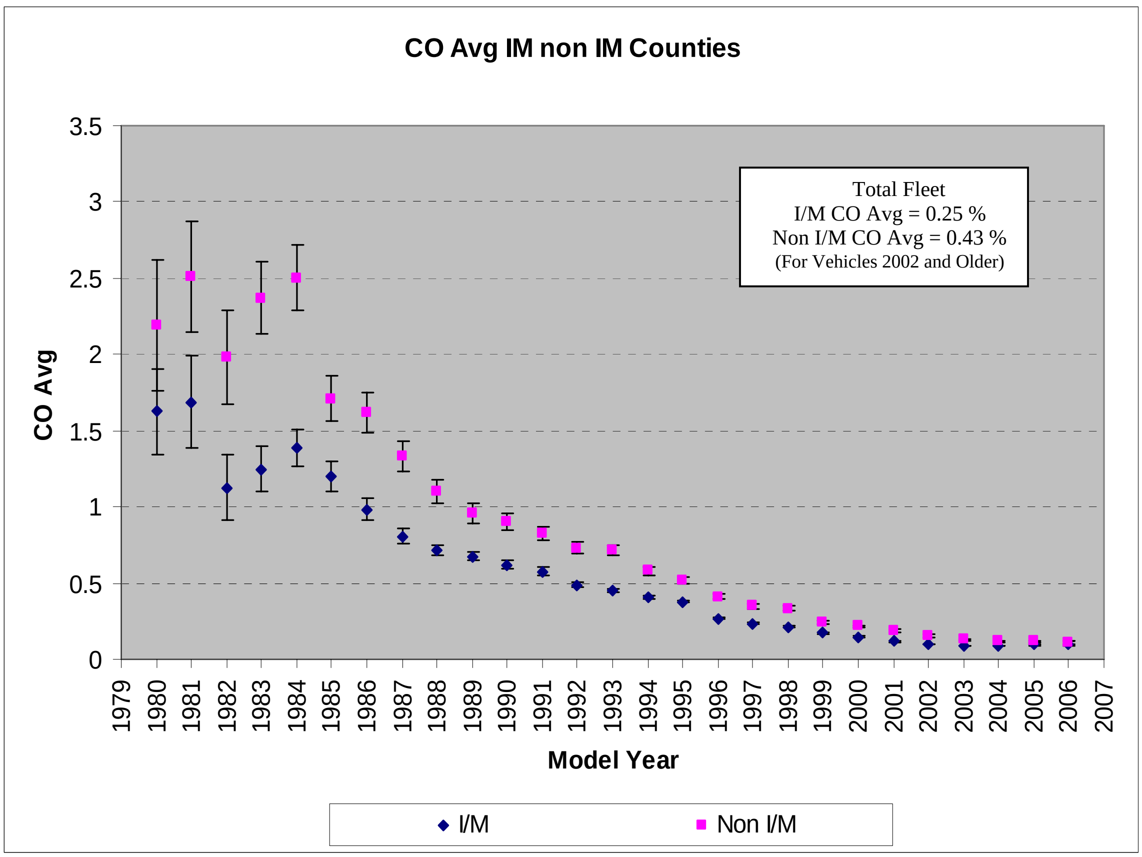
Figure 3. Distribution of Measurement by County Type



I/M Counties vs. Non I/M Counties

In this section we will compare the fleet of vehicles from the Atlanta Metro Area that has an annual emission inspection, to fleet of vehicles that are registered in counties without an I/M program. To see if a difference between I/M and Non-I/M counties exists, we need to select vehicle groups that can be compared. For this purpose we use the vehicle's model year information that was decoded from the VIN obtained from the Georgia RDB. CO measurements were averaged and plotted for each model year for I/M and non-I/M counties. As can be seen in Figure 4, measurements from newer vehicles (i.e. first few model years) are almost identical but when vehicle become 5 years old and older differences between I/M and Non-I/M vehicles become increasingly pronounced. Averages for model year 2002 and older vehicles are 0.25 % for I/M and 0.43% for Non-I/M counties respectively.

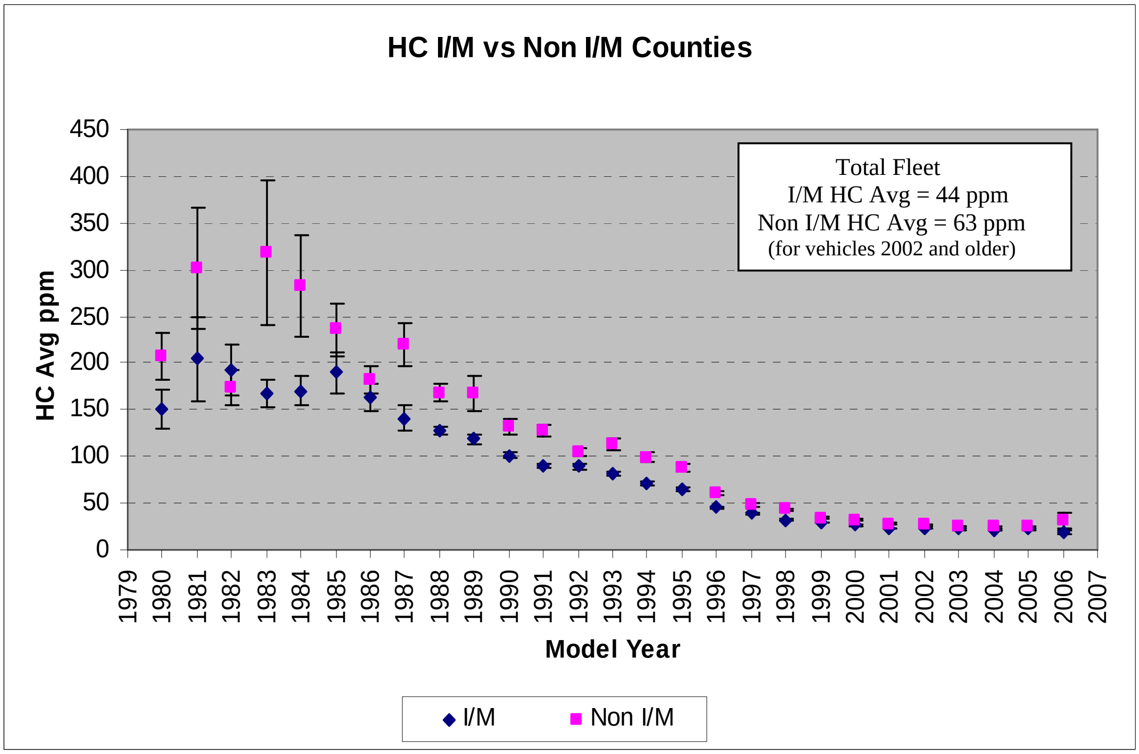
Figure 4. CO Exhaust Concentrations for I/M and Non-I/M Vehicles



We can draw similar conclusion for the HC averages plotted by model year for the I/M and Non-I/M fleet shown in Figure 5. For newer vehicles, the averages are almost the same whereas for older vehicles the comparison shows a much dirtier fleet for the

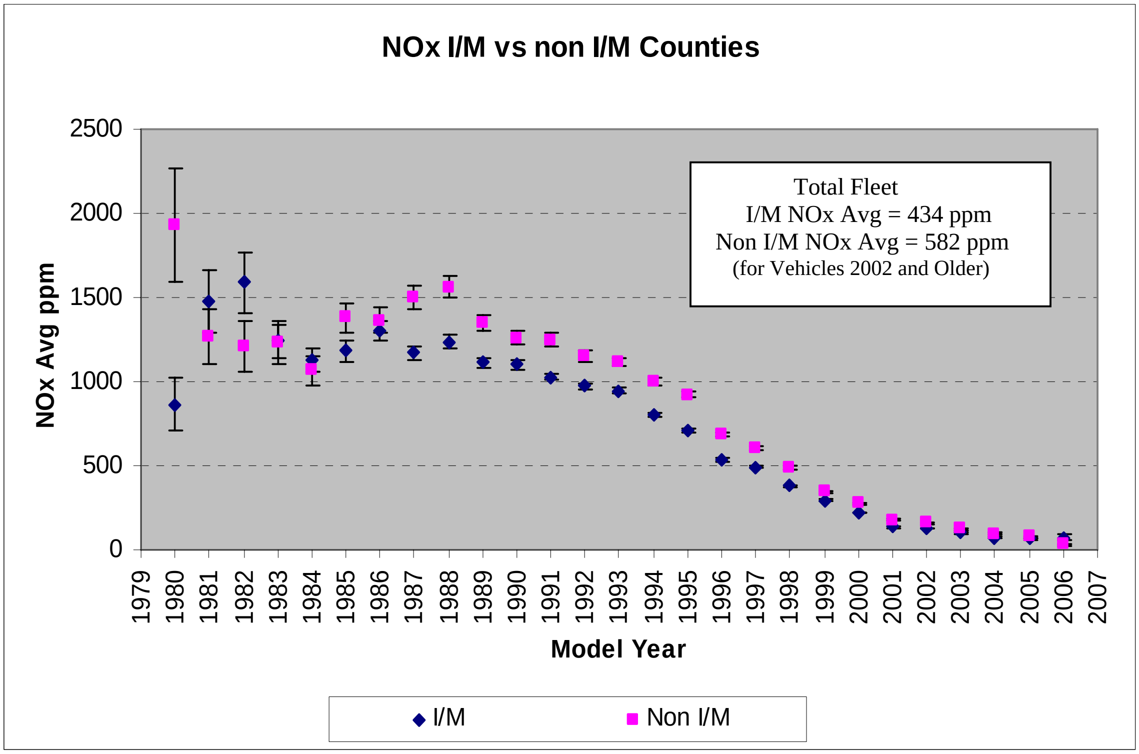
Non-I/M counties. HC Averages for vehicles older than 2001 are 44 ppm for I/M and 63 ppm for Non-I/M counties respectively.

Figure 5. HC Exhaust Concentrations for I/M and Non-I/M Vehicles



NO also follows the same trend as for CO and HC (Figure 6). For newer model years NO is virtually the same but for older model years differences begin to appear.

Figure 6. NO Exhaust Concentrations for I/M and Non-I/M Counties



Vehicle Specific Power

Vehicle Specific Power (VSP) is the measure that attempts to normalize vehicle power requirements by using physical characteristics of the site and driving conditions. It uses the site's slope and vehicle's speed and acceleration as input parameters

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VSP can be calculated as:

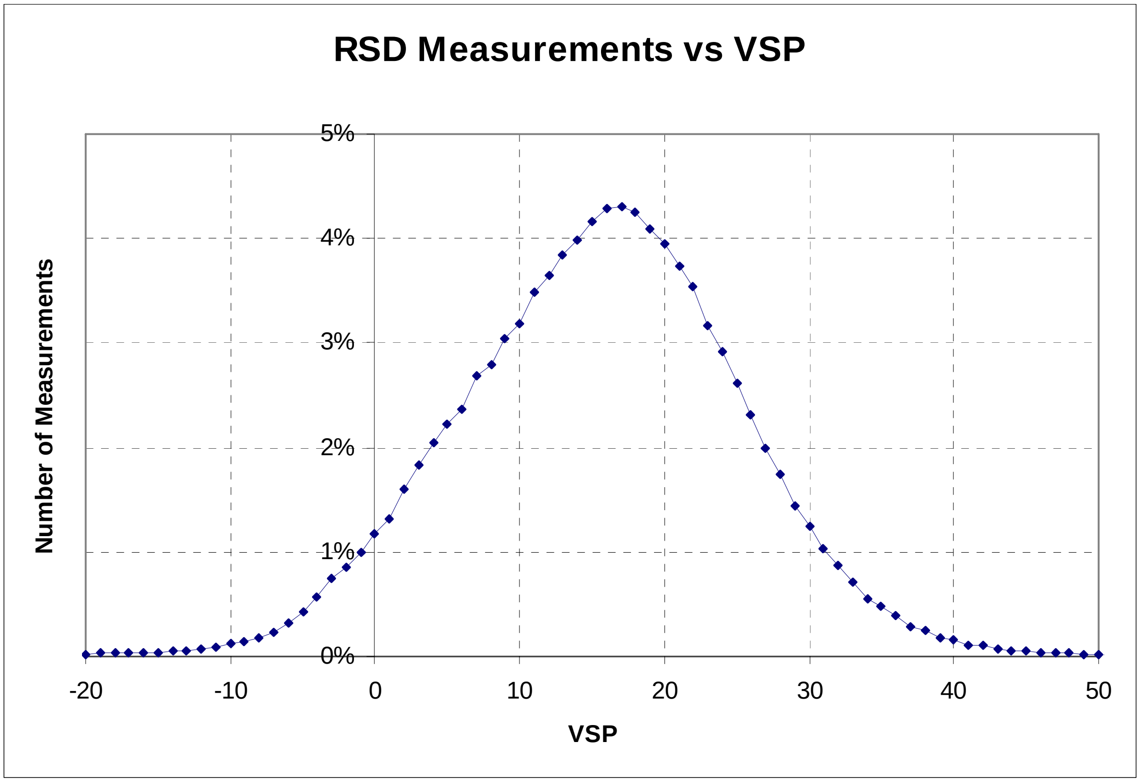
$$VSP = 4.39 * \sin(Slope) * V + 0.22 * V * A + 0.0954 * V + 0.0000272 * V^3$$

Where V is Speed in MPH, and A is Acceleration in MPH/s, VSP is in KW/metric tonne.

Example: For a vehicle traveling 40 MPH with an acceleration of 1 MPH/s at the site with 2 degrees upgrade will have VSP =19.6 KW/tonne (16 HP/short ton).

Figure 7 illustrated the observed VSP distribution for the whole measured fleet.

Figure 7. VSP Distribution for CAFÉ Measurements



To further understand how load on the engine affects vehicle exhaust concentrations, the fleet was divided into vehicle-age groups and CO, HC and NO averages were plotted against VSP. These results are shown in Figures 8, 9 and 10 respectively. CO and NO are generally affected by higher VSP conditions whereas HC is higher for negative and very low VSPs. We also can see how different groups of vehicle are affected.

Figure 8. Observed CO versus VSP for CAFÉ Measurements

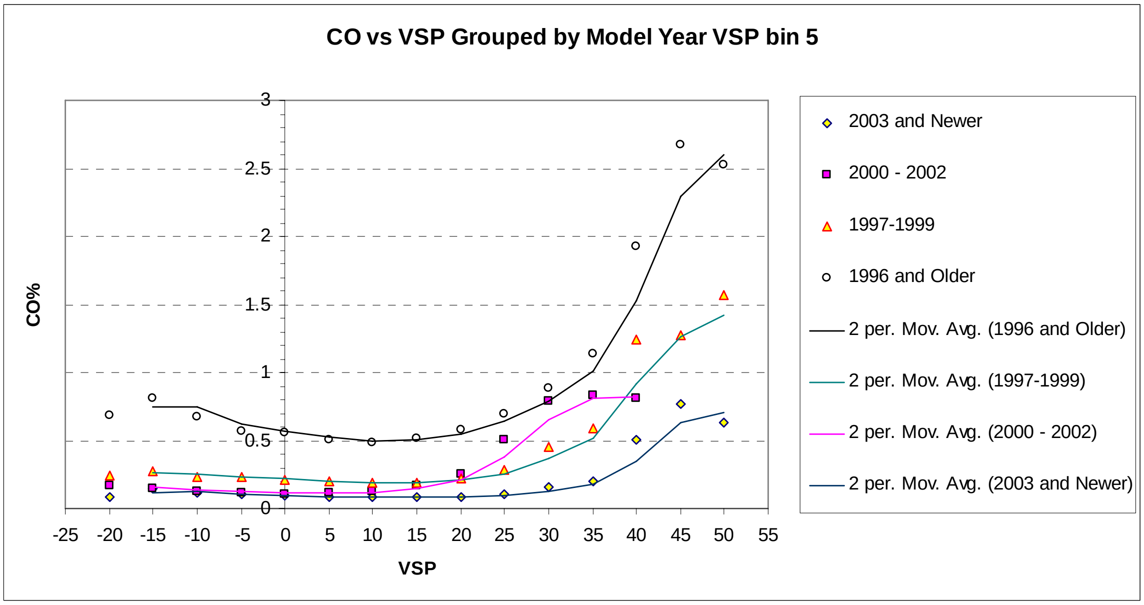


Figure 9. Observed HC versus VSP for CAFÉ Measurements

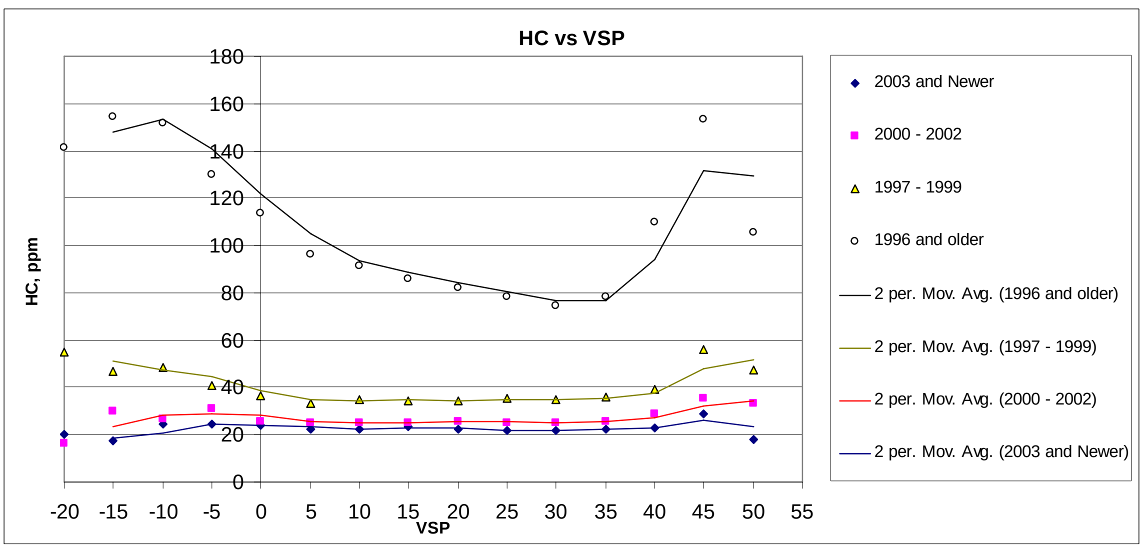
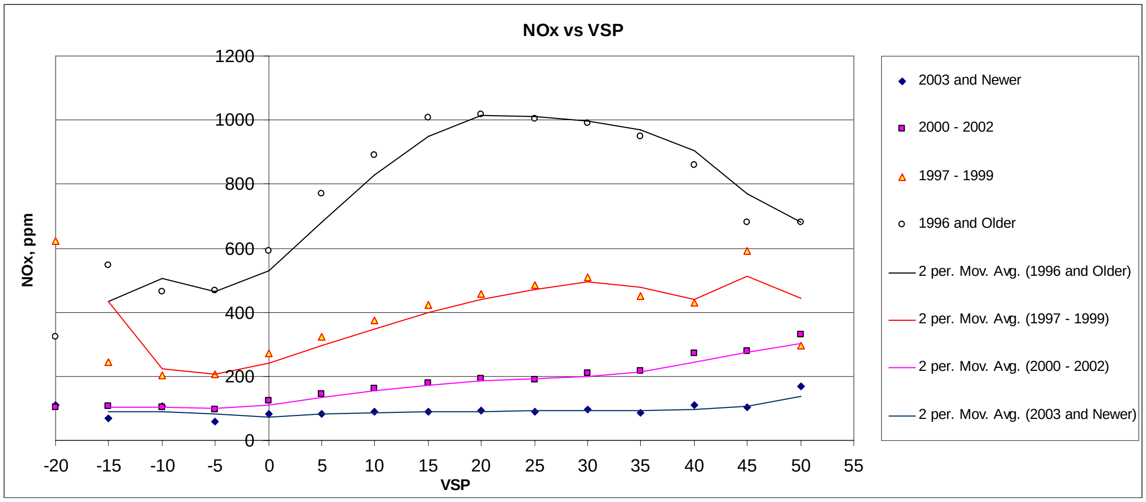


Figure 10. Observed NO versus VSP for CAFÉ Measurements



These curves can assist us in identifying ranges for which high-emitters might be identified. We also might consider applying different working range limits for different model years. For instance, newer vehicle behave similarly for wider range of VSP whereas older vehicles do not. In addition, since emission components (CO, HC, and NOx) react dissimilarly to power requirements at high and low VSP we might introduce separate range for each component and age group in high emitter identification or clean screening. These options are considered in the following section.

High Emitter Analysis

As a secondary objective to its primary mission of monitoring and evaluating the condition of the light-duty motor vehicle fleet operating in the Atlanta area, the CAFÉ program has sought to identify high-emitting vehicles observed during the measurement program for subsequent follow up activities.

It has been established in many studies that a large fraction of vehicle emissions originate from relatively small fraction of gross polluting vehicles. Estimations of contribution of gross polluters vary from study to study, because they depend on composition of fleet and study methodology, but as a whole they indicate that the dirtiest 10% of sampled vehicle fleets produced 60% to 70% of the total CO, 42% to 79% of the total HC, 32% to 80% of the total NO. As a result of their disproportional contribution to the on-road emissions inventory, gross polluters play in important role in the anticipated emission reductions that states try to achieve through control of in-use vehicles. Evaluations of the California I/M program demonstrate that Smog Check emission reduction derives largely from the identification and subsequent repair or replacement of gross emitting vehicles (1)

Important feature of high emitting vehicles, which complicates their identification, is the inherent instability of emissions, which produces a high level of fluctuations: short-term (fraction of a second) and long term (hours or even days) (1, 2).

High emitters can be:

- Vehicle that has high emissions all the time
- Vehicle that has high emissions intermittently
- Vehicle that has high emissions only in certain driving modes.

The definition of high emitting vehicles and their classification has changed with time as technology improved and older carbureted vehicles were replaced by electronic ignition systems, the quality of catalytic converters increased, and fully computerized systems of emission control were introduced. In various studies high emitter were defined:

- Relative to local fleet
- Relative to specific cut points
- Relative to certification standards.

Relative to the local fleet high emitters can be identified based on emissions of the 10% dirtiest vehicles or as the proportion of vehicles accounting for 50% of total emissions (3). Specific cut points used in RSD studies varies from 2.4% to 4% for CO and from 250 ppm to 440 ppm for HC (4).

In EPA's Mobile6 model, high emitters are identified as exceeding 2*Standard for HC and NO and 3*Standard for CO and are chosen based on the data on I/M and repair programs. They have been shown to be a good dividing point between high emitting broken vehicles, which can be significantly improved after repair, and low emitting vehicles, which are not broken. The design of OBDII systems is supposed to produce a warning signal by illuminating the malfunction indicator light (MIL) when conditions in engine and/or emissions control system may produce emissions exceeding 150% of the selected standard.

In any program of remote sensing identification of high emitters, a vehicle that was identified by a remote sensing device (RSD), has to be tested on local I/M station on an ASM or IM 240 system. Comparison of this kind has been done in several programs. In spite of significant scatter of readings for an individual vehicle, there is a good correlation of RSD data with ASM data when averages over large amount of similar vehicles (model year and type) are considered.

Figure 11 shows the dependence on model year of average CO reading (CO_avg) for the **total volume** of available RSD and ASM CAFÉ data in the current project. Figure 12 shows the correlation of CO_avg over model year for the groups of the **same vehicles** observed in the CAFÉ project by RSD and at the ASM test for years 2000 – 2005.

Figure 11: CO Averages for RSD vs. ASM for All Vehicles

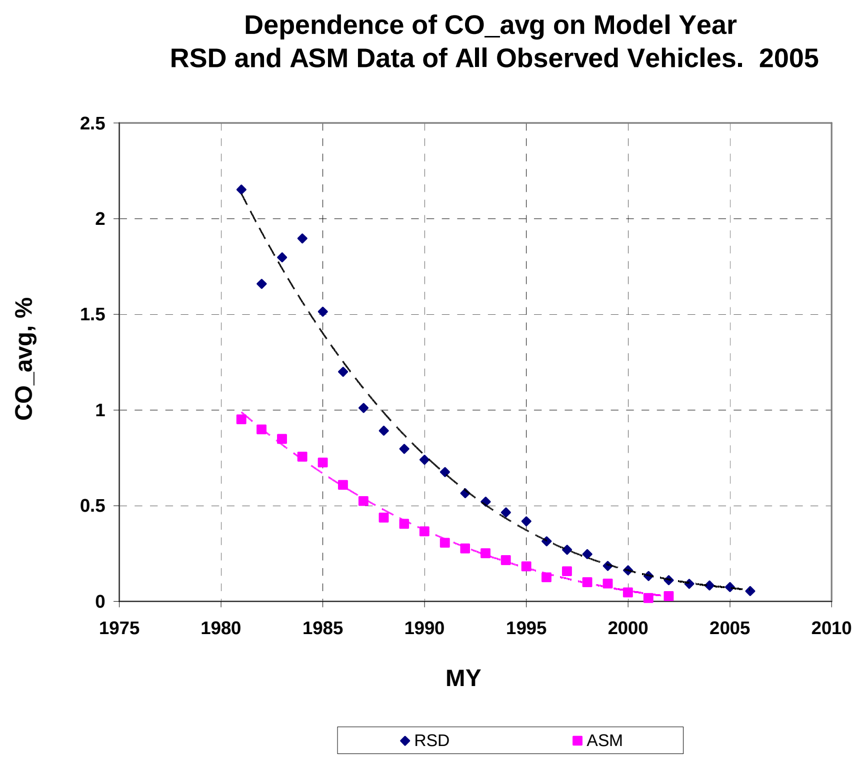
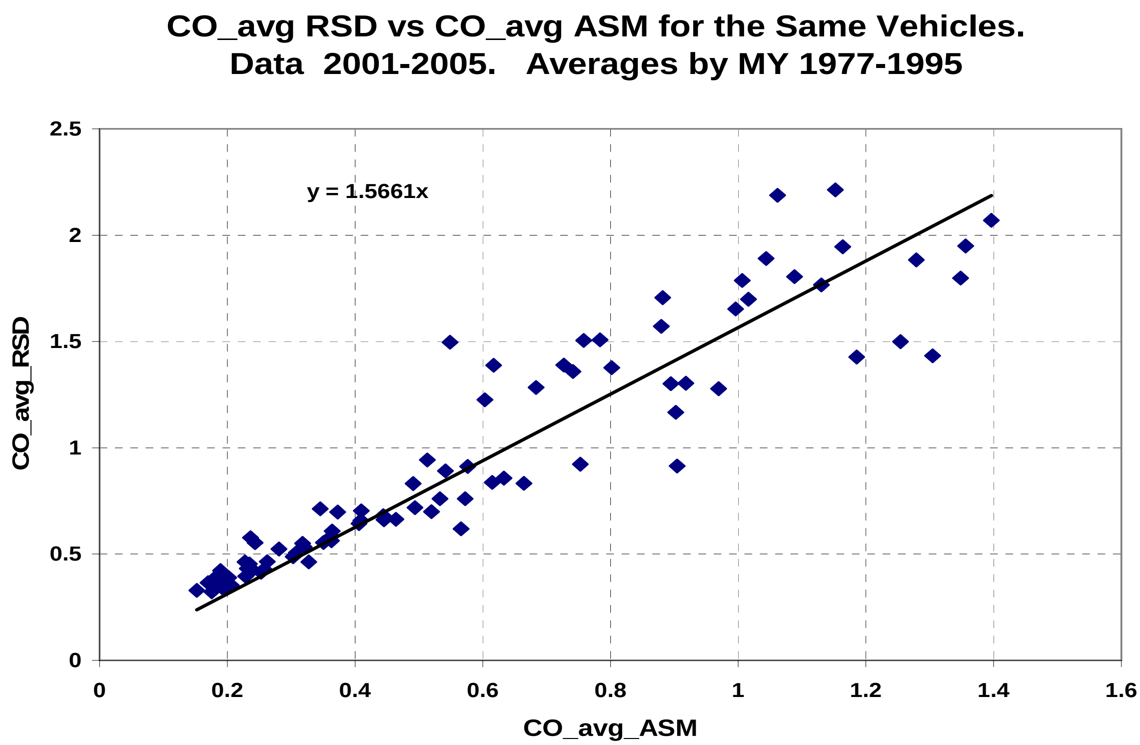


Figure 12: CO Averages for RSD vs. ASM for Same Vehicles



Ordinary least-squares linear regression produces following dependences:

CO_avg_RSD = 1.57*CO_avg_ASM
HC_avg_RSD=1.26*HC_avg_ASM
NO_avg_RSD=1.6*NO_avg_ASM

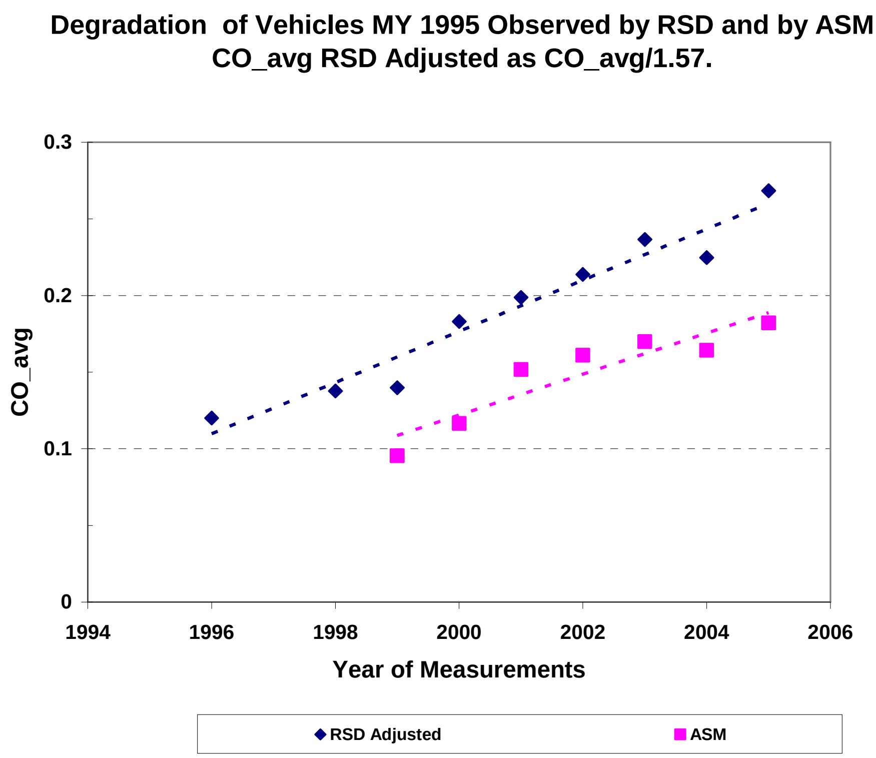
Similar dependences exist in literature although the coefficients differ from study to study because of their dependence on fleet composition and on the distribution of VSP in the sampled fleet.

In Figure 13 we compare the degradation of vehicles from model years 1996 – 2005 of CAFE RSD data and for period 2000-2005 for 13 county Atlanta ASM data. On this graph we use CO_adj for RSD readings, defined by formula above. The data are fairly close.

Based on these relations we introduce RSD standard - equivalents of ASM standards. RSD standards in complete analogy with ASM standards depend on vehicle type and model year (according to ASM tables). They may be considered as an approximate boundary for definition of the fraction of the fleet responsible for excessive emissions. Figure 14 shows a comparison of percentage of readings exceeding RSD standards with the percent of ASM test failures. The result are close, but as a whole fraction of high emitting vehicles estimated from remote sensing is higher than from the

I/M data. The reason is that remote sensing readings represent wide range of driving modes and they are collected under various loads, including significantly higher ones than the I/M test.

Figure 13: ASM versus RSD Estimated Degradation Rates



When it comes to comparison for individual vehicles and observations made at different times, the scatter of remote sensing readings becomes an important factor. Figure 15 gives histograms of CO ASM and RSD distributions for the relatively small group of vehicles measured by RSD and ASM in close temporal proximity. For Figure 15, we selected RSD observations performed not later then 10 days after an ASM test for vehicles that passed the ASM test. For RSD data CO_adj=CO/1.57 is used. Evidently, no changes happened to the vehicles during this period. The difference shows that vehicles at ASM test look “cleaner”. However, comparison of individual readings shown in Figure 16 shows significant differences. Since the distribution of observations in Figure 16 is far from normal, data cannot be readily compared using ordinary linear regression and correlation. The rank correlation coefficient, which describes what fraction of readings lies in the same range of values of magnitude, is relatively low.[1]

[1] While for these conditions the individual measurement correlations are relatively low, under optimized conditions of experiment results correlations can be very close. In a California study in 1995 and in a current study in California, the experimenters have used two remote sensors positioned sequentially on the road to identify vehicles with emissions exceeding 4% CO and /or 1000 ppm HC on both instruments. These vehicles were pulled over for confirmatory ASM test. More than 90% failed.

Figure 14: RSD versus ASM Failure Rates

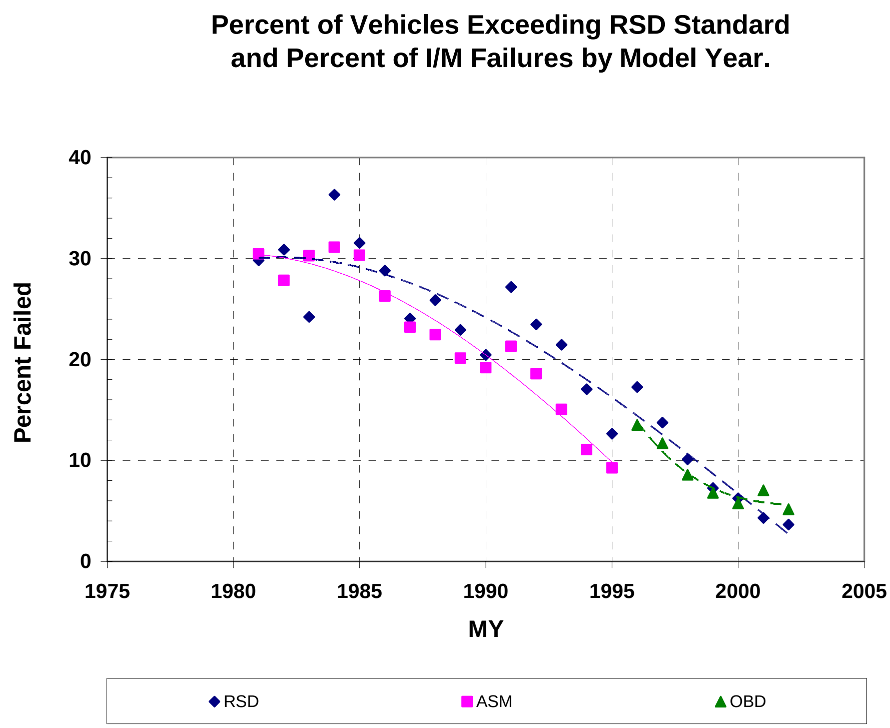
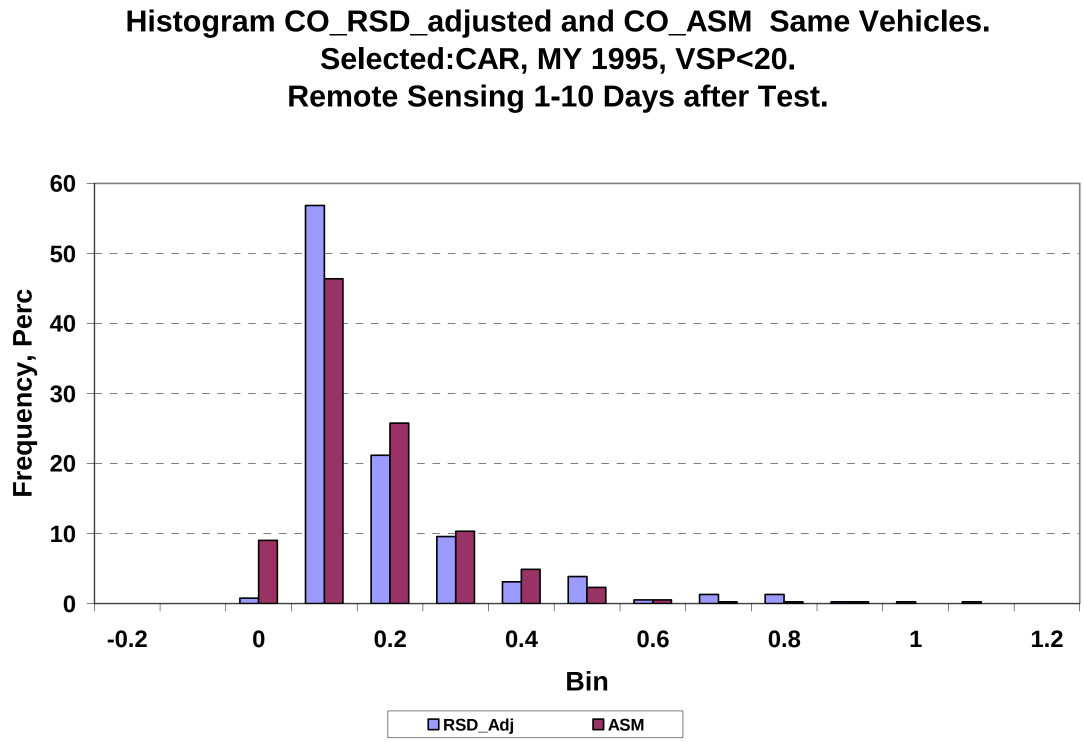
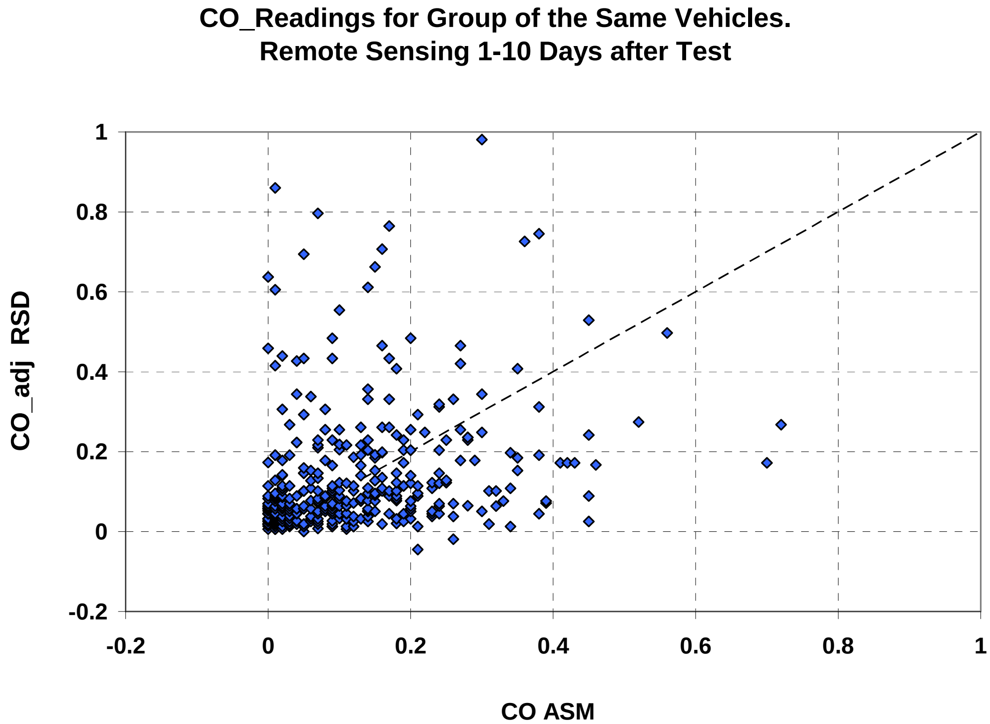


Figure 15: Histogram of ASM versus RSD Measurements (Same Vehicles)



	RSD_adj	*ASM*
Mean	0.146	0.120
Median	0.076	0.090
Mode	0.057	0.010
Standard Deviation	0.202	0.120
Count	387	387

Figure 16: Comparison of Individual Measurements



In this study, we have made comparisons of vehicles identified by RSD as high emitters using various criteria with the results of their corresponding ASM test. It should be noted that this kind of comparison is "in blind". This is, whenever a significant time period has elapsed between the RSD observation and the ASM test, there is a possibility that the vehicle has been repaired or has broken or been tampered with in the interval between the two tests and thus cannot be considered a prediction except in the most general sense. Since the purpose of our study is a fleet evaluation, we normally visit various sites and do not concentrate our efforts on the sites were large numbers of high emitters can be targeted. As result volume of data on two or more observations of the same high emitting vehicle is quite small.

At first we analyzed the problem of remote sensing measurement scatter based on results of multiple observations for a large number of vehicles in a wide range of concentrations. We used data from a variety studies conducted by the Georgia Tech Air Quality Laboratory. These included studies in Atlanta and projects performed in NY, NC, VT, MO, and VA during the years 1998 – 2002. In total these data included 884 vehicles with more than 20 observations (N>=20), 22,450 vehicles with 10<=N<=20 and 108,615 with 5<=N<=10. 6.1 percent of these data had CO_avg exceeding 1%, 2.3 percent had HC_avg exceeding 200 ppm , and 16 percent had NO_avg of more than 1000 ppm.

For purposes of analysis, each individual group was described by its descriptive statistics. Figure 17 illustrates the dependence of the standard deviation of the CO measurements as a function of the average CO reading (CO_avg) for a "typical" vehicle. It is evident from the graph that for a high emitting vehicle, an uncertainty interval of two standard deviations covers the whole measurement range.

Figure 17: Uncertainty of CO Measurements

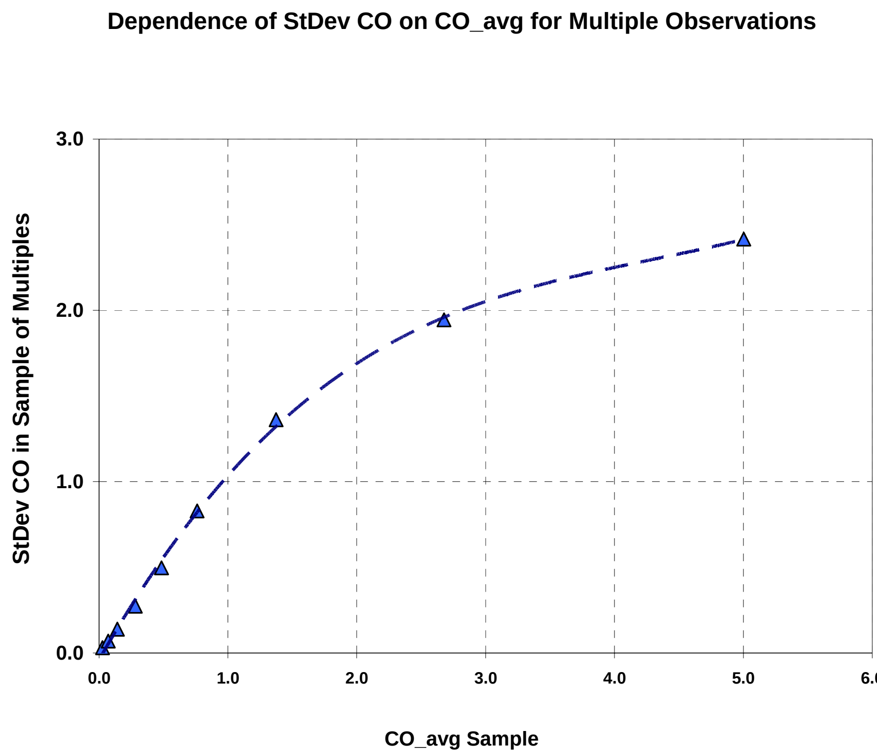


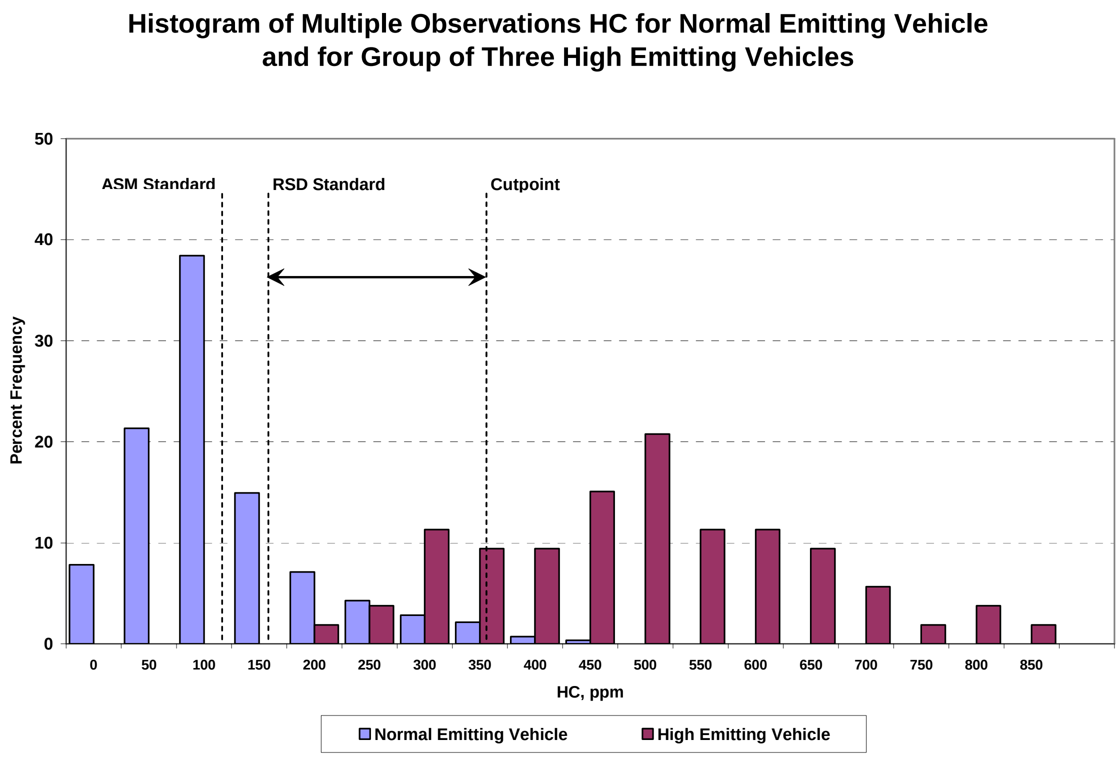
Figure 18 illustrates the problem of identifying selection cut points for high emitter identification. The figure shows the overlap of HC distribution of multiple observations for a normally emitting vehicle with the distribution of observations for three high emitters with very close mean and standard deviations. The figure also shows the ASM standard, the RSD standard and standard deviation at the point of the RSD standard. If we assume that ASM test produces the "average" for each of the vehicles, then we have to resolve the trade-off between incorrectly identifying a normal emitter as a high emitter with the failure to identify a significant number of high emitters, which will not be identified by RSD.

Selection of any fixed cut point for use in high emitter identification is also complicated by differences in standards for vehicles of different model years. ASM test standards for model years 1980 – 1995 ranges from 0.6 % to 3.7 % for CO; 100 ppm - 550 ppm for HC and 700 ppm –4900 ppm for NO. The lowest standards are applied to larger MY 1995 vehicles, and the highest to smaller vehicles from MY 1980[2]. Fixed cut points that are appropriate for large and medium cars and light duty trucks may not be

[2]Selected range is LDV weight >=1750 and <=4500 pounds , LDT weight >=2500 and <=7000 pounds.

applicable for older small cars. For vehicles MY 1996 and newer, the corresponding ranges are smaller: 0.36% -0.8 % for CO, 65 ppm – 140 ppm for HC, and 470 ppm – 1200 ppm for NO. Fixed cut points may be useful for these vehicles.

Figure 18: Overlap of High Emitter and Normal Emitter Distributions



Normal Emitters

Mean	**40**
Median	**29**
Mode	**45**
Standard Deviation	**75**
Range	**351**
Count	**139**

High Emitters

Mean	**464**
Median	**463**
Mode	**490**
Standard Deviation	**171**
Range	**854**
Count	**63**

To test the applicability of various cut point strategies, we divided the measurement exceeding selected threshold in three ranges: intermediate (or "suspect" – flag H1), high (flag H2), and very high ("super emitters" – flag H3). Various levels or various combinations of levels can be applied for specific separation of vehicles by age (vehicles of 2005 and 1996 have the same standards, but they differ significantly), the previous history of the vehicle, for multiple observations and for correlated CO-HC high emitters (according to (5) more than 60% of dirtiest 10% emit excessive HC and CO simultaneously). From a total number of 24,377 vehicles subject to ASM test 19,904 were matched to I/M records, 9050 of them had RSD measurements before the ASM test.

Several selections of thresholds were tested because success rate, which is defined as a ratio of the number of vehicles failed RSD to the number of vehicles failed I/M test, turned out to be lower than was initially anticipated.

The following thresholds were used:

1. 1*ASM_stand, 2*ASM_stand, 3*ASM_Stand

2. RSD_stand, RSD_stand+StDev_RSD, RSD_stand+2StDev_RSD

3. Two fixed sets of cut points: 220 ppm HC, 1.2 % CO, 700 ppm NO and 440 ppm HC, 2.4 %CO, 1400 ppm NO.

Results of various tests are similar: the highest emitting vehicles are present in any case; the difference is in total number of vehicles exceeding levels H1, H2 and H3 and in their selection. Total success rate varies slightly.

Results for the first set of thresholds (based on ASM Standards) are present in the Tables 1, 2, and 3. They can be summarized as follows. From total number of 9050 readings of vehicles subject to ASM test and having RSD observations before the ASM test, on the first threshold (level H1 and higher) 3,538 suspect and high emitters were selected. Their fraction of the total fleet is 39% and they emit 75 % of total estimated emissions. Success rate for this group is 27.05%. On the next step, 1,138 high emitters exceeding level H2 (working range) were selected. They correspond to 12.6% of vehicles and they produce about 40% of the emissions total. Success rate for this group is 33.5%. In this group, we selected 25% of dirtiest; they are responsible for 50% of excessive emissions produced by high emitters. Success rate for them is 71%, for the remaining 75 % the success rate is 21%. It is important to note that most of them are correlated high emitters CO-HC. In Appendix D we provide additional analyses of these vehicles.

As we can see, remote sensing selects the dirtiest vehicles with high efficiency. Vehicles that have highest readings at the time of the ASM test have the highest probability of being identified by RSD. It is in accordance with experience mentioned above in successful applications of RSD.

Since our study is not oriented specifically towards search of high emitters (HE), we had relatively low number of vehicles with two observations: 166. We did not have any pair with combinations of measurements above threshold level H2H3. All pairs had combinations H1H1 or H1H2. Success rate for these vehicles was 34.4%. That is 7 % higher than for single observations in the same group and higher than for single observation in the main group H2H3.

Success rate was higher for the second set of thresholds (combinations of RSD Standard and StDev RSD). Total number of suspect and high emitters, exceeding first level - RSD Standard - was 1983 (almost the same as for the previous case), the success rate for this group was 31.4%. On the next level, 673 vehicles were selected with a success rate for this group of 36.3%. For correlated CO-HC emitters on this level, the success rate is 42.1% for a total of 152 vehicles. Table 4 shows the increase in success rate as conditions of selection become stricter. At the same time the size of sample available for analysis decreases dramatically as illustrated in Figure 19. Eventually, we can reach 100% success rate but only 3 vehicles out of the initially selected 673 remain.

The appearance of a high number of false failures by remote sensing is difficult to explain, because many vehicles showed high emissions on the road before their ASM test, but passed the test. For example, we made several observations of MY 1995 vehicles with CO>6% and HC>1000 ppm (level H3 – super emitters). It is far higher than the maximum possible error of RSD; however they passed the test with low readings on both pollutants. We cannot exclude possibility of repairs or maintenance work on some of these vehicles between the time of RSD observations and the ASM tests.

Similar analysis was done for vehicles of MY 1996 – 2005 subject to OBD testing. From a total of 77,486 vehicles subject to OBD testing, 63,528 were matched to IM test data. 27,091 of them had RSD observation before the OBD test. In the first approach (based on ASM standards) initially 4,573 suspect and high emitters were selected. Success rate for this group was 13.9%. The group for the next step (exceeding 2*ASM standard) consisted of 1,222 vehicles with a success rate 17.8%. The best result was for the group of correlated CO-HC high emitters: 24.1% of 104 vehicles. Similar results with a lower number of selected vehicles and higher success rate were obtained in the second approach based on the RSD standard and StdDev RSD. Table 5, similar to Table 4, and Figure 20 summarize results for these tests.

Table1

Total matched to ASM (RSD before Test)			Fraction of HE	CO	HC	NO
				Contribution of HE to total Emission of Sample		
9050	Selected HE H1H2H3	3538	39.09%	74.80%	70.16%	67.94%
Failed ASM Test						
1190	Selected HE H2H3	1138	12.57%	44.79%	37.27%	24.71%

Table 2

		Success rate		CO	HC	NO
				Contribution to Emission in the group H2H3		
Total HE H2H3		33.50%		100.00%	100.00%	100.00%
1138	Dirties 25% (285)	70.53%		48.62%	74.59%	32.77%
	The rest 75% (853)	21.15%		51.38%	25.41%	67.23%

Table 3. Multiple observations

Observations in Original full Table (H1H2H3)	3538
Success rate	27.05%
Two or three observations	342
Unique Vehicles	166
Success rate	34.34%

Table 4. Comparison of RSD data to ASM test data under various conditions of selection HE. Threshold1=RSD Standard

Group of HE	Number of HE Identified by RSD	Failed ASM Test	Success Rate
All Pollutants H1H2H3	1983	622	31.37%
All Pollutants H2H3	673	244	36.26%
CO H2H3 and HC H2H3	152	64	42.11%
CO H3 and HC H1H2H3	82	36	43.90%
CO>6%	53	26	49.06%
CO>6% and HC H2H3	43	23	53.49%
CO>6% and HC>200 ppm	40	22	55.00%
CO>7.5% and HC>200 ppm	21	14	66.67%
CO>9% and HC>200 ppm	11	8	72.73%
CO>10% and HC>300 ppm	3	3	100.00%

Figure 19: High Emitter Identification Success Rate for ASM Based Standards

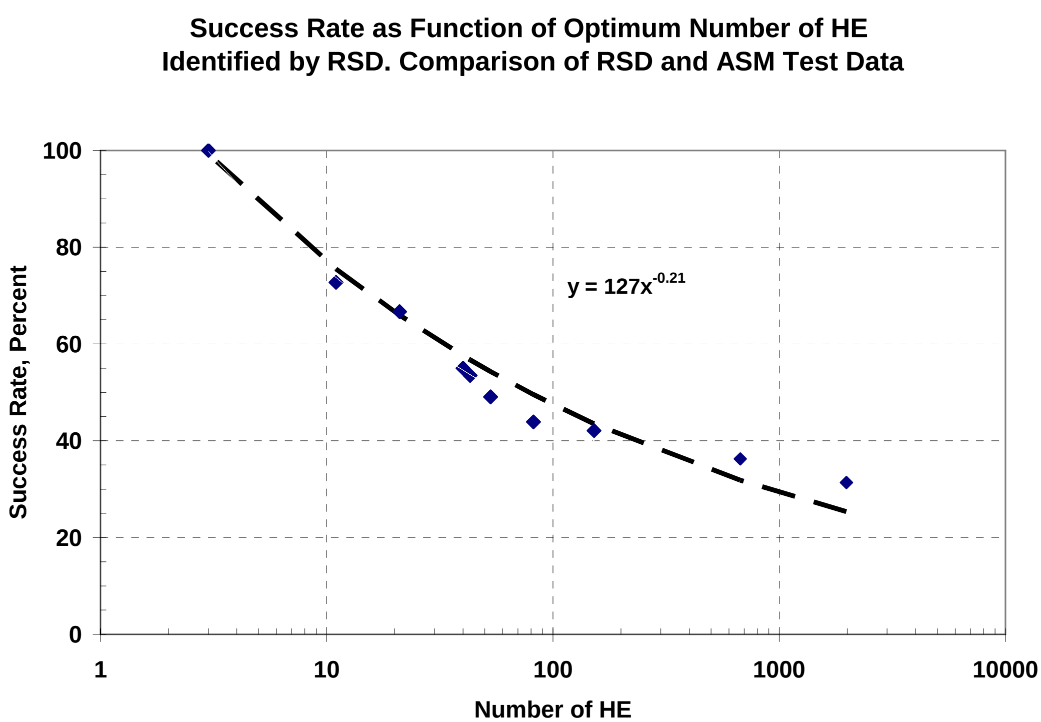
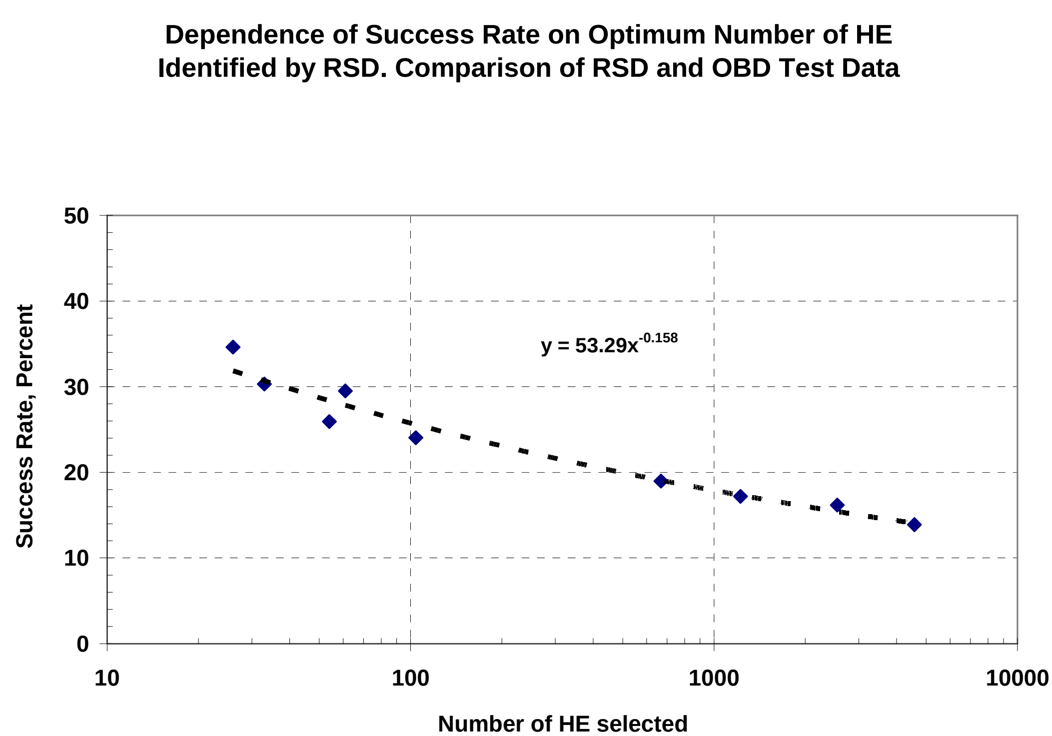


Table 5. Comparison of RSD data to OBD Test data under various conditions of selection HE

	Group of HE	Total number of HE identified by RSD in the Group	Failed IM Test	Success Rate
Threshold1= ASM_Standard	All Pollutants H1H2H3	4573	635	13.89%
	All Pollutants H2H3	1222	210	17.18%
	Correlated CO-HC H2H3	104	25	24.04%
Threshold1= RSD_Standard	All Polluitants H1H2H3	2548	412	16.17%
	All Pollutants H2H3	669	127	18.98%
	Correlated CO-HC type H2 and H3	54	14	25.93%
	CO type H3, HC type H2 and H3	61	18	29.51%
	CO H3, HC>210 ppm	33	10	30.30%
	CO>4%, HC>210 ppm	26	9	34.62%

Figure 20: High Emitter Identification Success Rate for RSD Based Standards



Summary and Conclusions

It is important to note that under similar conditions success rate for the OBD test is significantly lower than for the ASM test. A similar result was reported in study (4). These authors mention that based upon data collected in California's ASM test program, OBD identifies about 30 to 40 % of the excess ASM emissions. As follows from our results only correlated CO-HC high emitters can be properly identified. OBD does not produce any malfunctioning code directly related to emissions. Codes describing malfunctioning of specific engine components are not sufficient for that purpose.

It is evident from these results that for increasing success rate it is necessary to have two observations and additional piece of information regarding vehicle (profiling). A high emitter index, which describes probability of vehicles of various make, model and model year to fail test, previous history of I/M tests for a vehicle, age, change of ownership and other factors of maintenance, which may influence quality of vehicle may be a valuable adjunct to remote sensing readings to improve on road high emitter identification. This methodology exists in most programs, which currently are working on the first stages of developing a complete HE identification scheme.

Appendix

Appendix A: CAFÉ Measurement Sites

Site ID	Location	City	County	Grade (Degrees)	Average Speed (MPH)
101	From Sigman Rd to I-20 east	Atlanta	ROCKDALE	-3.5	30
103	On State Route 74 just South of Willow Rd and Paschall Rd	Peachtree City	FAYETTE	2.5	30
105	From SR 53 to I - 985 South	Gainesville	HALL	4	30
108	From Hwy 27 to SR 166 East	Carrelton	CARROLL	-2	25
112	From SR 142/81 to I - 20 West	Covington	NEWTON	0	25
15	Thorthon Rd To I-20 East	Douglass	DOUGLAS	2	41.22
16	From Chapel Hill Rd to I-20 East	Douglass	DOUGLAS	-2.3	39.29
22	From SR120 to GA 400 South	Roswell	FULTON	0	37.82
24	From Abernathy Rd to GA400 South	Sandy Spring	FULTON	5	31.18
35	On SR 34 West after Intersection with US 29/SR 14	Coweta	COWETA	0.5	30
36	From SR 34 to I-85 North	Coweta	COWETA	5	37.58
37	From I-75/85 South to I-20 West	Fulton	FULTON	1.5	52.4
40	From Mt.Zion to I-75 North	Clayton	CLAYTON	2	48.31
42	From Jimmy Carter Blvd to I-85 North	Gwinnett	GWINNETT	-4.5	45.42
48	From Barrett Parkway to I-75 South	Kennesaw	COBB	5	44.31
5	From Marrietta Parkway to I-75 South	Marietta	COBB	2.5	35.7
74	From Peachtree Pkwy to Peachtree Ind Blvd	Gwinnett	GWINNETT	3	17.35
80	From Memorial Dr to I-285 North	Dekalb	DEKALB	-1	49.5
81	From SR 20 to GA 400 South	Cumming	FORSYTH	-3.5	40
90	SR20E & SR140E to I-575 1/2m From SR20	Canton	CHEROKEE	0	45
97	From West Ave and Klondike Rd to I-20 west (Exit 80)	Conyers	ROCKDALE	-1.5	46
98	From Sixes Rd to I-575 South	Lebanon	CHEROKEE	0	47
AUG2	Whitesboro Rd to I-520 West	Augusta	RICHMOND	3.5	40
AUG7	From Peach Orchard Rd. to I -520 West	Augusta	COLUMBIA	5.5	40
AUG8	From Wheeler Rd to I-520 East	Augusta	COLUMBIA	0	30
MAC2	Coliseum Drive to I-16 West (At Macon Coliseum)	Macon	BIBB	0.5	37.88
MAC9	From Arkwright Rd and Tom Hill Sr Blvd to I-75 South	Macon	BIBB	1	27
TLS5	Northside Parkway to I-75 North	Atlanta	FULTON	7.5	40

Appendix B: Data Collection Days

Measurement Date	RSD Unit Number	Site ID	Beam Blocks	Valid Data	Readable License Plates	Matched to RDB	VIN Decoded
10/18/2004	503	24	11035	10612	9705	8376	7481
10/21/2004	503	24	11914	11467	10158	8668	7632
10/26/2004	503	42	10000	9118	7856	6667	6012
10/28/2004	503	42	7171	6520	5611	4776	4307
11/4/2004	503	74	9418	8758	7951	7015	6188
11/5/2004	503	74	11400	10562	9537	8538	7553
11/9/2004	503	37	11300	9232	7494	6203	5624
11/18/2004	503	37	12700	9548	7917	6385	5748
11/19/2004	503	80	8000	7234	6250	5390	4947
12/3/2004	503	80	7777	6937	5834	5073	4650
12/14/2004	503	48	8184	7497	6028	5120	4485
12/15/2004	503	48	7469	6904	5382	4545	3903
12/16/2004	503	5	5000	4469	4298	3587	3160
1/12/2005	503	5	4660	4083	3564	2943	2542
1/13/2005	503	81	5481	4857	4339	3763	3170
1/20/2005	503	22	7814	7327	6543	5393	4484
1/26/2005	503	98	5555	4416	3243	2813	2416
1/27/2005	503	90	5000	4245	3524	3045	2613
2/4/2005	503	97	3636	3258	2423	1993	1721
2/10/2005	503	101	2121	1785	1520	1306	1135
2/11/2005	503	15	7667	6411	5508	4521	3937
2/16/2005	503	16	4940	4701	3880	3287	2858
2/17/2005	503	40	3748	3457	2942	2477	2175
2/25/2005	503	36	6461	5874	4877	3999	3345
3/2/2005	503	35	4499	3910	3579	3074	2644
3/3/2005	503	105	6060	5621	4838	4262	3656
3/9/2005	503	112	2500	2137	1849	1622	1394
3/10/2005	503	105	6000	5546	4673	4084	3477
3/15/2005	503	108	3758	3427	3061	2688	2282
3/18/2005	503	24	8686	8346	7027	5951	4952
3/30/2005	503	16	5210	4982	4136	3459	2956
4/4/2005	503	15	8000	6589	5488	4638	3994
4/18/2005	503	97	3414	3080	2557	2130	1825
4/25/2005	503	101	2222	1825	1643	1465	1245
5/6/2005	503	36	6666	6070	5403	4490	3676
5/11/2005	503	90	3232	2876	2565	2283	1899
5/19/2005	503	MAC9	5252	5105	4571	4046	3469
5/20/2005	503	MAC2	3131	2952	2677	2461	2163
5/21/2005	503	MAC9	1840	1794	1656	1405	1154
5/25/2005	503	103	7500	6583	5867	5248	4351
5/27/2005	503	MAC2	5555	5281	4690	4191	3698
5/28/2005	503	MAC9	3080	3005	2624	2172	1813
6/9/2005	503	103	7008	6411	5311	4697	3805
6/10/2005	503	98	6900	5793	4956	4508	3654
6/16/2005	503	40	4003	3731	3058	2608	2211
6/17/2005	503	35	5010	4330	3550	3079	2636
6/23/2005	503	22	9011	8479	6993	6226	5047
6/24/2005	503	5	5890	5408	4632	3965	3272

7/8/2005	503	42	10300	9555	7694	6469	5347
7/22/2005	503	16	5235	4989	3943	3404	2825
8/25/2005	503	80	8260	7578	6646	5833	4979
8/26/2005	503	36	6336	5710	4643	3932	3083
8/27/2005	503	105	4000	3877	3258	2944	2385
8/30/2005	503	AUG7	4390	4100	3469	2940	2534
8/31/2005	503	AUG7	9702	8958	7864	6774	5776
9/1/2005	503	AUG2	6010	5716	5261	3863	3218
9/2/2005	503	AUG8	6300	6095	5404	4387	3659
9/3/2005	503	AUG2	3600	3443	3127	2208	1805
9/8/2005	503	TLS5	5525	5413	4773	4288	3335
9/14/2005	503	MAC9	3426	3313	2891	2591	2161
9/15/2005	503	MAC2	5890	5605	5098	4707	4058
9/16/2005	503	MAC9	3744	3622	3237	2813	2275
		Totals:	**385596**	**350527**	**301096**	**257788**	**220799**

Appendix C: Data Collection by County Group

CAFÉ Contract October 1, 2004 - September 31, 2005

	All Counties (Plan 360,000)	Urban Core Counties (Plan 175,000)	Suburban Ring Counties (Plan 115,000)	Reference Counties (Plan 70,000)	
		4 "Urban" counties	9 Suburban Counties	8 Exurban Counties	Macon-Augusta
4Q 2004	121368	121368	0	0	0
1-3 Q 2005	264229	60143	119844	22318	61923
Totals:	**385596**	**181514**	**119844**	**84241**	

Appendix D: Analysis of Correlated High Emitters CO-HC

Among the dirtiest 25 % of high emitters identified by ASM, a significant fraction failed the ASM test for both CO and HC. Many of these vehicles are also identified as both CO and HC high emitters by the CAFÉ data. Table A1 shows this group. It has been stressed in the literature (5) that approximately 60 % of all HE are correlated CO-HC and it is important to consider the data from this point of view.

For this kind of analysis it is appropriate to use an approach from non-parametric statistics of using the distribution of readings by ranks. CO and HC readings in the total group of 1138 suspect and high emitters (H1H2H3) were ranked by increasing value of their CO readings. The highest reading has rank 1 with subsequent measurements ranked according to its position in the group (same readings have equal ranks). The largest rank for CO is 1093; the largest rank for HC is 1136. A cumulative approach was used: readings were arranged according to the increase in the sum of ranks (SUM). Success rate (SR) was a calculated as a function of upper value of SUM. The range of SUM was 4 – 2229. These results are presented in Figure D1. The meaning of graph is as follows: variable Y defines success rate (SR) for a group of readings with sum of ranks equal or lower than X.

From this graph we can obtain range of values of CO and HC for a given success rate. If we select success rate of 0.75 as an acceptable, than corresponding SUM is 600. Figure D-2 shows the correlation of readings for CO and HC in the range of SUM 580 – 620. For HC we scale HC/100 to have variables in the same range. If we exclude the highest values of CO and HC, as representing HE of CO and HC only (not correlated), the rest of the range shows fairly good correlation, which can be described by equation in the figure. Transforming the variables CO_ASM and HC_ASM to their RSD equivalents we come to the equation:

$$LN(CO\_RSD)+1.31*LN(HC\_RSD/100) =-0.66$$

This equation gives additional information for evaluation of correlated high emitters CO-HC in the range CO 0.25 – 055 % and HC 85 – 160 ppm: if expression on the left side of equation exceeds -0.66 then the estimated success rate should exceed 75%.

Figure D-1 Rank Sum of CO and HC Measurements

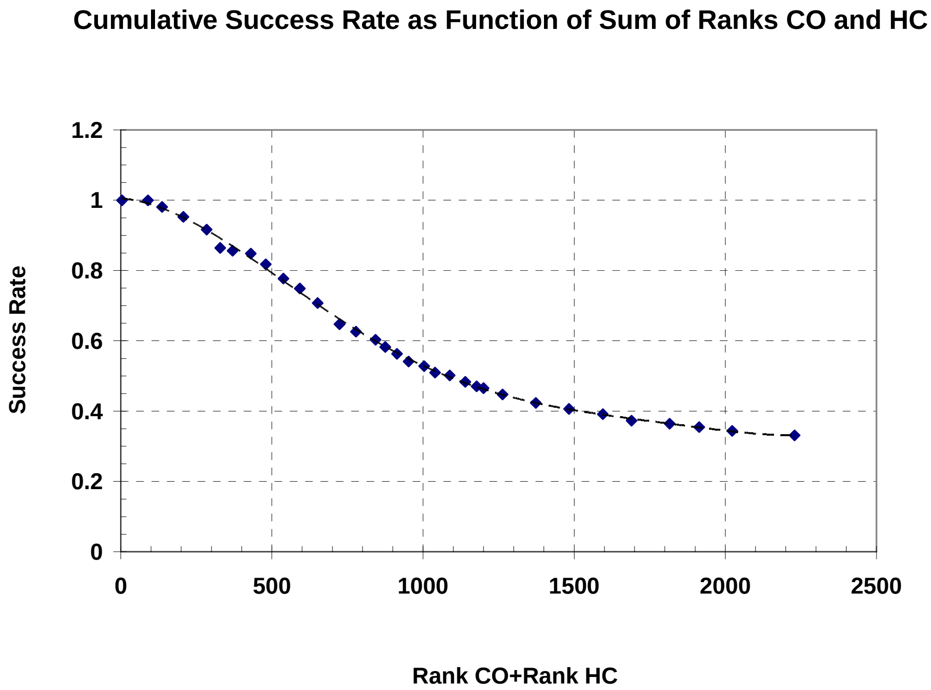
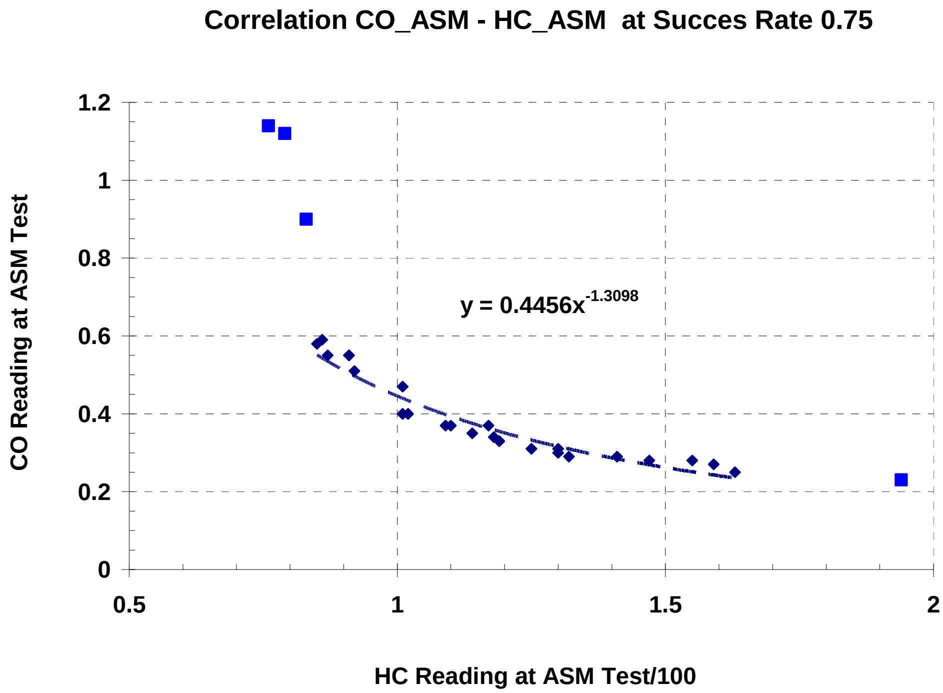


Figure D-2 Correlation of CO and HC Estimates



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